HARVARD COLLEGE OBSERVATORY

HARVARD UNIVERSITY

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STUDY OF GROUND-BASED AND SPACE VEHICLE INFRARED INSTRUMENTATION FOR THERMAL PHOTOGRAPHY OF THE MOON, INCLUDING EXPERIMENTAL PROGRAMS AT SELECTED OBSERVATORIES

SEMIANNUAL STATUS REPORT NO. 13

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Co-Investigator: Hector C. Ingrao

Data Reduction - Programming

During the current reporting period, all of the efforts of the data reduction group have been directed toward the completion and the "debugging" of the integrated data processing package LUNAR. This package will permit the computer to use our new measurement data cards as input and provide as output a printout of brightness temperatures as well as store this output on magnetic tapes. A new flow chart (Fig. 1) is included herein which depicts the current flow of data through this new package system. Also included is Fig. 2, a block diagram which reflects the electronic circuitry of the radiation pyrometer relevant to the processing of the radiant power on the infrared detector.

This package LUNAR, in addition to brightness temperatures also provides other data of physical significance (see attached Table) but has the advantage over our previous system in that the data is stored on magnetic tapes instead of cards. This package also permits all of the separate programs, subprograms and routines to be performed as one computer operation creating great savings in the cost of cards and card storage. Our card storage problems are now minimum whereas under our former system we would have had to use several large rooms or more just to store the voluminous accumulation of punched cards.

All of the existing infrared data will be processed through this integrated program LUNAR to give us brightness temperatures covering a substantial portion of the lunar disk. The details and workings of this package has been fully described in Scientific Report No. 9.

Lunar Excursion Module (LEM)

During this period and in cooperation with Arthur D. Little we made a study of the thermal response of the lunar surface at the landing site during the descent of the LEM. This analysis is on the thermal response at the landing site due to the radiative and convective heat transfer from the LEM exhaust nozzle. A computer program has been written to analyze the thermal transients as a function of: 1) the thermal model of the lunar surface materials; 2) depth beneath the lunar surface; 3) distance from the touchdown point. The physical meaning of the answers obtained in our analysis depends on how accurate the heat transfer parameters are for the assumed model, during the LEM descent. Therefore we prefer to stress the method of analysis rather than the numerical conclusions.

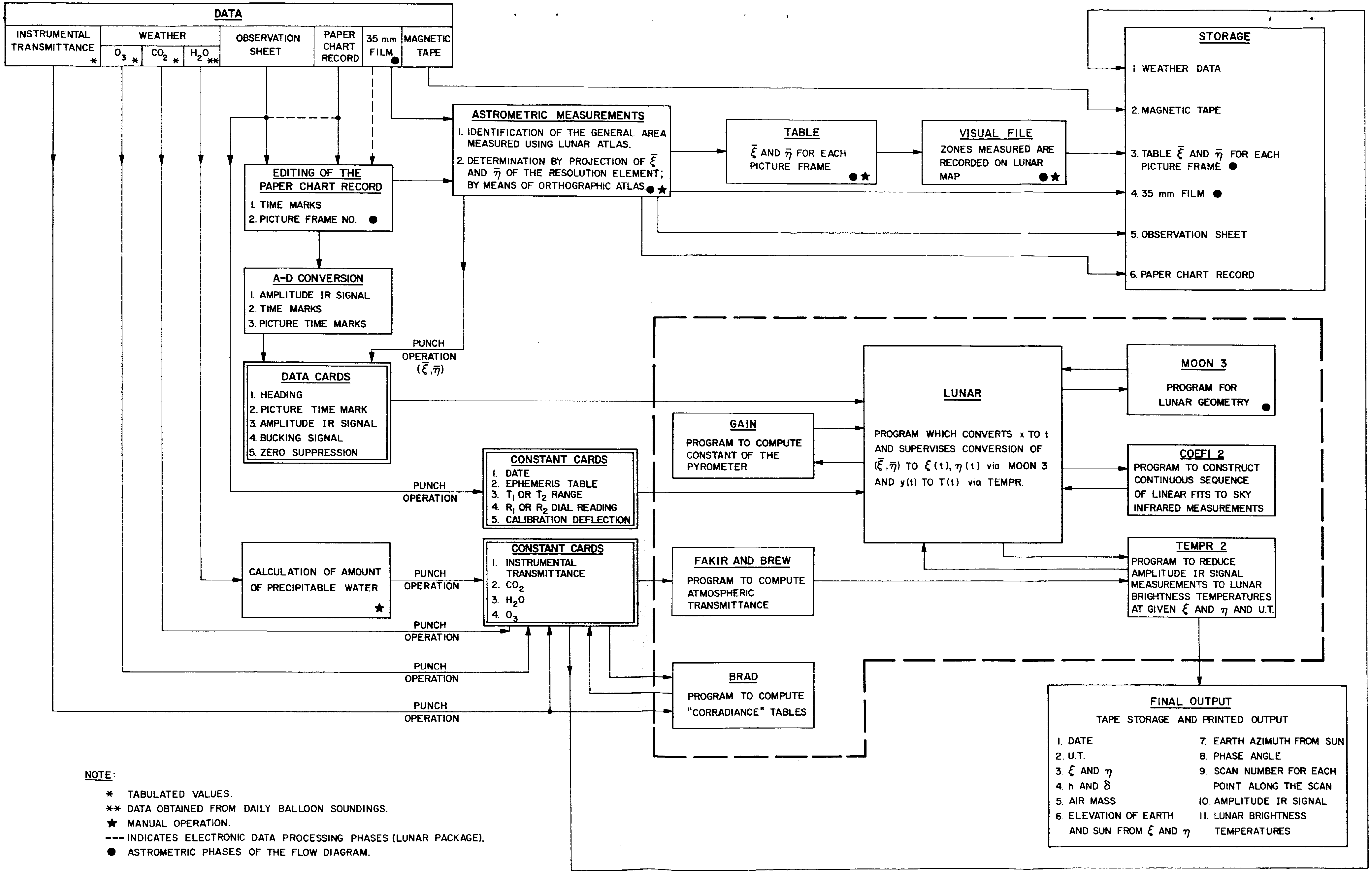
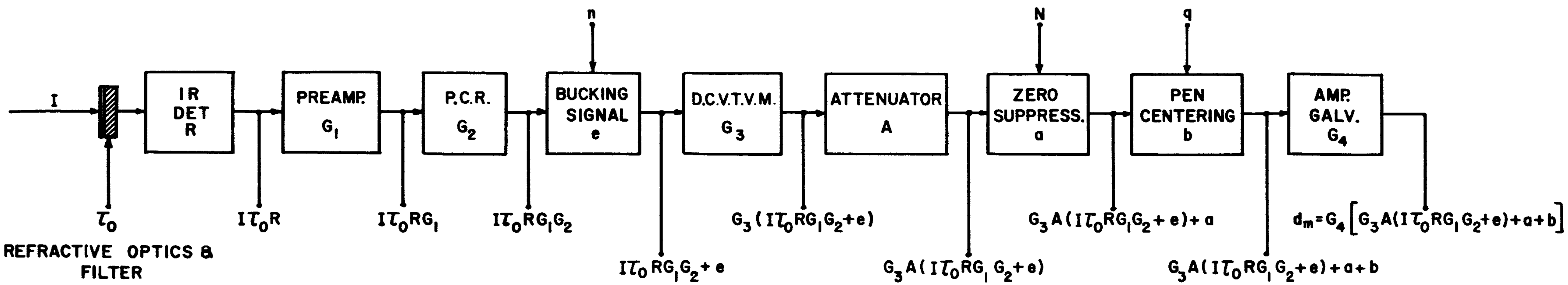


FIG. 1. Block diagram of the Data Processing system developed at Harvard College Observatory.



A = ATTENUATION RATIO AT THE INPUT OF THE AMPLIFIER GALVANOMETER
a = ZERO SUPPRESSION, V
b = PEN CENTERING VOLTAGE, V
c = CONSTANT OF THE BUCKING SIGNAL COUNTER (watts per increment)
d = TOTAL DEFLECTION OF THE RECORDING PEN, mm
d_m = OBSERVED DEFLECTION OF THE RECORDING PEN, mm
e = BUCKING SIGNAL, V
G_1 = PREAMPLIFIER VOLTAGE GAIN
G_2 = PHASE CONTROL RECTIFIER VOLTAGE GAIN
G_3 = DIRECT CURRENT VACUUM TUBE VOLTMETER GAIN
G_4 = AMPLIFIER GALVANOMETER GAIN
I = RADIANT POWER ON THE DETECTOR, W
K(t) = CONSTANT OF THE PYROMETER, $W\,mm^{-1}$
N = ZERO SUPPRESSION, GIVEN IN COUNTER READING
n = BUCKING SIGNAL, GIVEN IN COUNTER READING
q = PEN CENTER DEFLECTION, mm
R = DETECTOR RESPONSIVITY, $V\,W^{-1}$
τ_0 = INSTRUMENTAL TRANSMITTANCE

FIG. 2. Block diagram of the electronic circuitry of the radiation pyrometer, relevant to the processing of the radiant power on the infrared detector.

TABLE

COMPUTER OUTPUT OF THE DATA PROCESSING OF LUNAR INFRARED MEASUREMENTS AT HIGH SPATIAL AND RADIOMETRIC RESOLUTION TO OBTAIN BRIGHTNESS TEMPERATURE AND OTHER RELEVANT ASTROMETRIC DATA

EPHEMERIS AND TEMPERATURE DATA OF LUNAR SURFACE SCAN 1

SCAN NO.	DATA 1965 APR NO.	D	H	M	SEC	XI	ETA	AIR MASS	ELEVATION OF EARTH	SUN	EARTH AZM. FROM SUN	PHASE ANGLE		TEMPERATURE DEGREE K
1	560	15	1	7	41.60	-0.8281	-0.3512	2.057	22.6	11.5	0.3	11.2		295.02
1	561	15	1	7	41.80	-0.8315	-0.3495	2.057	22.3	11.1	0.3	11.2		293.03
1	562	15	1	7	42.01	-0.8350	-0.3477	2.057	21.9	10.8	0.3	11.2		289.99
1	563	15	1	7	42.21	-0.8384	-0.3460	2.057	21.6	10.4	0.3	11.2		286.84
1	564	15	1	7	42.41	-0.8419	-0.3442	2.057	21.2	10.0	0.4	11.2		286.84
1	565	15	1	7	42.57	-0.8445	-0.3429	2.057	20.9	9.8	0.4	11.1		285.76
1	566	15	1	7	42.82	-0.8487	-0.3407	2.057	20.5	9.3	0.4	11.1		283.58
1	567	15	1	7	43.08	-0.8531	-0.3384	2.057	20.0	8.8	0.5	11.1		283.58
1	568	15	1	7	43.18	-0.8548	-0.3375	2.057	19.8	8.6	0.5	11.1		283.58
1	569	15	1	7	43.39	-0.8584	-0.3357	2.057	19.4	8.2	0.5	11.1		282.47
1	570	15	1	7	43.59	-0.8619	-0.3338	2.057	19.0	7.8	0.5	11.1		280.21
1	571	15	1	7	43.85	-0.8664	-0.3315	2.057	18.4	7.3	0.5	11.1		279.06
1	572	15	1	7	44.00	-0.8691	-0.3301	2.057	18.1	7.0	0.6	11.1		276.72
1	573	15	1	7	44.70	-0.8725	-0.3283	2.057	17.7	6.6	0.6	11.1		275.53
1	574	15	1	7	44.41	-0.8761	-0.3263	2.057	17.2	6.1	0.6	11.1		271.85
1	575	15	1	7	44.61	-0.8798	-0.3244	2.057	16.8	5.6	0.6	11.1		270.59
1	576	15	1	7	44.82	-0.8834	-0.3224	2.057	16.3	5.2	0.7	11.1		268.00
1	577	15	1	7	45.02	-0.8871	-0.3204	2.057	15.8	4.7	0.7	11.1		265.34
1	578	15	1	7	45.23	-0.8909	-0.3184	2.057	15.3	4.2	0.7	11.1		266.67
1	579	15	1	7	45.43	-0.8946	-0.3163	2.057	14.7	3.6	0.7	11.1		263.96
1	580	15	1	7	45.63	-0.8982	-0.3143	2.057	14.2	3.1	0.8	11.1		263.96
1	581	15	1	7	45.84	-0.9021	-0.3122	2.057	13.6	2.5	0.8	11.1		259.71
1	582	15	1	7	46.04	-0.9060	-0.3100	2.057	13.0	1.9	0.8	11.1		255.21
1	583	15	1	7	46.25	-0.9099	-0.3078	2.057	12.4	1.3	0.8	11.1		250.41
1	584	15	1	7	46.45	-0.9139	-0.3055	2.057	11.8	0.6	0.8	11.1		247.02
1	585	15	1	7	46.66	-0.9180	-0.3032	2.057	11.0	-0.1	0.9	11.1		245.26
1	586	15	1	7	46.81	-0.9211	-0.3014	2.057	10.5	-0.6	0.9	11.1		239.68
1	587	15	1	7	47.07	-0.9261	-0.2984	2.057	9.5	-1.6	0.9	11.1		235.67
1	588	15	1	7	47.22	-0.9294	-0.2964	2.057	8.9	-2.2	0.9	11.1		235.67
1	589	15	1	7	47.42	-0.9339	-0.2936	2.057	7.9	-3.2	1.0	11.1		224.28
1	590	15	1	7	47.63	-0.9387	-0.2907	2.057	6.8	-4.3	1.0	11.1		224.27
1	591	15	1	7	47.83	-0.9438	-0.2873	2.057	5.5	-5.6	1.0	11.1		216.10
1	592	15	1	7	48.04	-0.9496	-0.2833	2.057	3.8	-7.3	1.0	11.1		216.09
1	593	15	1	7	48.24	-0.9528	-0.2822	2.057	0.	0.	0.	0.	OFF	-0.
1	594	15	1	7	48.45	-0.9556	-0.2810	2.057	0.	0.	0.	0.	OFF	-0.
1	595	15	1	7	48.65	-0.9585	-0.2798	2.057	0.	0.	0.	0.	OFF	-0.
1	596	15	1	7	48.85	-0.9614	-0.2785	2.057	0.	0.	0.	0.	OFF	-0.
1	597	15	1	7	49.06	-0.9643	-0.2773	2.057	0.	0.	0.	0.	OFF	-0.
1	598	15	1	7	49.21	-0.9664	-0.2764	2.057	0.	0.	0.	0.	OFF	-0.
1	599	15	1	7	49.42	-0.9693	-0.2752	2.057	0.	0.	0.	0.	OFF	-0.
1	600	15	1	7	49.62	-0.9722	-0.2739	2.057	0.	0.	0.	0.	OFF	-0.
1	601	15	1	7	49.83	-0.9750	-0.2728	2.057	0.	0.	0.	0.	OFF	-0.
1	602	15	1	7	50.03	-0.9779	-0.2715	2.057	0.	0.	0.	0.	OFF	-0.
1	603	15	1	7	50.23	-0.9807	-0.2703	2.057	0.	0.	0.	0.	OFF	-0.
1	604	15	1	7	50.44	-0.9836	-0.2691	2.057	0.	0.	0.	0.	OFF	-0.
1	605	15	1	7	50.64	-0.9865	-0.2679	2.057	0.	0.	0.	0.	OFF	-0.
1	606	15	1	7	50.85	-0.9894	-0.2666	2.057	0.	0.	0.	0.	OFF	-0.
1	607	15	1	7	51.05	-0.9922	-0.2655	2.057	0.	0.	0.	0.	OFF	-0.
1	608	15	1	7	51.26	-0.9951	-0.2642	2.057	0.	0.	0.	0.	OFF	-0.
1	609	15	1	7	51.46	-0.9979	-0.2630	2.057	0.	0.	0.	0.	OFF	-0.
1	610	15	1	7	51.67	-1.0008	-0.2618	2.057	0.	0.	0.	0.	OFF	-0.
1	611	15	1	7	51.87	-1.0037	-0.2605	2.057	0.	0.	0.	0.	OFF	-0.
1	612	15	1	7	52.07	-1.0066	-0.2593	2.057	0.	0.	0.	0.	OFF	-0.
1	613	15	1	7	52.28	-1.0088	-0.2584	2.057	0.	0.	0.	0.	OFF	-0.
1	614	15	1	7	52.48	-1.0123	-0.2569	2.057	0.	0.	0.	0.	OFF	-0.
1	615	15	1	7	52.69	-1.0151	-0.2557	2.057	0.	0.	0.	0.	OFF	-0.

This analysis was carried out for eight different lunar surface models and temperatures were obtained as a function of: 1) depth; 2) time elapsed from beginning of descent; and, 3) distance from point of touchdown. The plotting of the results for the homogeneous vesicular material is given in Figure 3.

This work was support work for part of the Apollo Program carried out by Grumman Aircraft as the main contractor. This work was accomplished with the cooperation of the Harvard Computing Center.

Observations

Up to June 30th the total observing for this project is reflected in the following table.

Lunar Day	Estimated Percentage covered (no overlap)
4	9.5%
5	11.0%
8	16.5%
9	28.5%
11	45.0%
12	135.0%
13	23.0%
14	21.5%
17	18.0%
23	25.0%

Scientific Reports

Scientific Report No. 9 entitled, "Data Processing of Lunar Infrared Measurements at High Spatial and Radiometric Resolution to Obtain Brightness Temperatures," was prepared during this reporting period and has been distributed. Considerable effort was exerted by our staff on this report to make it complete and explain in detail exactly how our data reduction system now functions. The following is an Abstract of the report:

A unique data processing of lunar infrared measurements at high spatial and radiometric resolution to obtain brightness temperature is presented. This system takes into account all the instrumental parameters and observing conditions, including amount of ozone, carbon dioxide, and precipitable water along the path. Possible drifts in the instrument or changes in the sky emittance are also handled by the system. Moreover, for each line of scan the accuracy in the location

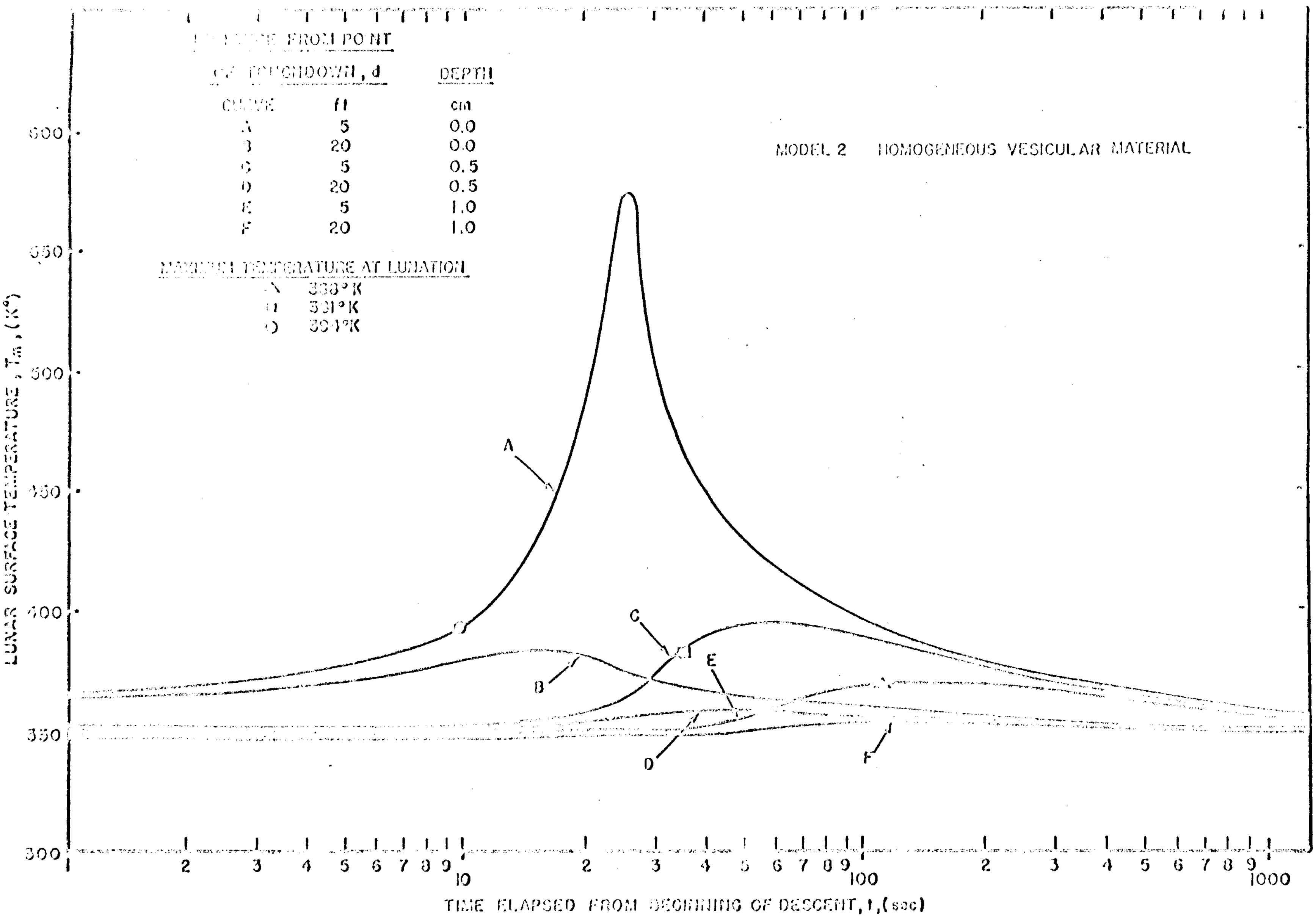


FIG. 3. Variation of surface and subsurface temperature vs. time (plots based on computer output).

of the resolution element on the lunar disk is also given, taking into account systematic errors such as the differential atmospheric refraction between visible and infrared rays.

The programming used in the data processing package produces a compact simplified data file oriented towards ease of retrieval of various forms (i.e., plotting of different subsets of the data). The techniques used to obtain this data file depend on a high degree of separation of different phases of the data-reduction. This separation is reflected in the organization of the program as a very simple supervisory program with many subroutines, each performing highly specific calculations.

A technical report entitled "A Study of Thermal Response of the Lunar Surface at the Landing Site During the Descent of the Lunar Excursion Module (LEM)" was prepared for Arthur D. Little Inc. and the National Aeronautics and Space Administration during this reporting period and has been distributed. The extent of this report is covered in Lunar Excursion Module (LEM) section.

Personnel

During this period we lost the services of our Observer who was on loan from the Smithsonian Astrophysical Observatory. On March 15th Mr. William H. Black Project Assistant on the staff of the Ionospheric Observatory (Cornell University) of Arecibo, Puerto Rico joined our staff as the Senior Observer for Agassiz Station. Mr. Black is a very careful and skilled observer and we are sure that our project will benefit from his contribution.

During the current reporting period the personnel has been held to a minimum. This was due to the fact that Mr. Black had to be trained in infrared measurements and consequently very little new data could be obtained. Moreover, the weather was most uncooperative during this reporting period. All casual and part-time help in data reduction were released and will be rehired during the coming period.

Future Plans

Observations - We plan to continue observing during the lunar night at wavelengths in the 8-14 microns range at our Agassiz Station. Budgetory limitations do not permit observations at longer wavelengths or at other locations.

<u>Data Reduction</u> - This phase of our work will continue as planned. Observations will be reduced to tables of temperature as a function of lunar coordinates and angles of illumination as well as other relevant astrophysical data.

<u>Property</u> - Major items of equipment (over $1,000) are being reported separately by Harvard's Office for Research Contracts.

Removed

<u>Financial Report</u> - The attached monthly statement for June 30, 1966 shows the expenses for various categories for the closing month of this report period, and cumulative expenses from the beginning of the report period.

Hector C Ingrao

Date: 7/26/66

Hector C. Ingrao
Co-Investigator